Thermal Conversion of Wastes to Hydrogen for Fuel Cell Applications

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Introductions

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What are the Energy Needs?
Now and in the Future.

- Energy from calorific waste streams.
- Distributed energy production.
- Distributed hydrogen production.
- Reduce dependence on fossil fuels.

The Startech Plasma Converter System and StarCell™ Hydrogen Separation System Can Satisfy These Needs.
Advantages of Thermal Plasma

- Superior Environmental Performance
- "Massless Heat"
- High Temperatures
- Recover Valuable Commodities: Hydrogen
- Low Gas Volumes

![Plasma Advantage for High Temperature Processing](image)
The Startech PCS
Feed Systems

- Loss-in-Weight Liquid Feed
  - Feed from drums or tank
  - Peristaltic pump with dedicated transfer hose
  - Metered steam blend and injection into vessel

- Multiple automatic solid feed configurations available based on feed materials:
  - Ram Feed
  - Shredder
  - Conveyor
  - Auger
  - Rotary Valve
Plasma Vessel

- Vessel
  - Two segment design
  - Main Vessel
  - Vessel Lid
  - Refractory lined walls
  - Sealed, negative pressure operation
  - Single PCG and melt exit port

- Melt Removal
  - Melt/Quench Cart
    - Continuous melt removal into water-cooled cart
    - Auger screw design
  - Tilt removal to side
Types of Plasma Torches

Twin Torch - Non-Transferred and Transferred Operation

Single Torch - Non-Transferred and Transferred Operation
Gas Polishing System

- Removes solids at three stages:
  - >10 microns, >1 micron, and >0.3 microns.
- Cools PCG™ in two stages:
  - ~1,400°C to 900°C, and 900°C to 40°C (10^4°C/second).
- Neutralizes and removes:
  - acid gases, nitrogen oxides, heavy metals, organic compounds.
- Removes entrained water and heats PCG™.
- Maintains negative pressure to pull PCG™ through system.
Cooling Water System

Plasma Skid

Chiller

DI CW System

Gas Polisher
Control System

- PLC Based control system
- Skid Mounted Control Panels with Remote I/O
- Centralized Operator Station
- PC Based Human Machine Interface
- Real-Time Video and Process Monitoring
The Startech PCS: Advantages

- Non-Combustion Reducing Vessel Atmosphere:
  - Dioxins/furans (<0.05ng TEQ/Nm³)
  - NOx (<50ppm)
  - 1/10th the gas flow of an oxidizing system, allowing much higher efficiency gas cleaning.

- Low Operating Cost:
  - Energy efficient
  - Highly automated
  - Low maintenance
  - Potential for sale of valuable products - HYDROGEN

- Low Capital Cost:
  - No secondary combustion chamber (as in oxidizing systems).
  - Smaller equipment to handle lower gas flow volumes
  - Standardized designs/components allow shorter delivery schedule
  - Skid-mounted modular equipment for lower installation cost
  - Standard commercial off-the-shelf (COTS) components
Plasma Processing of MSW - Thermodynamics

- Thermodynamic analyses with air and CO/H2 as plasma media.
- Steam used to convert C to CO, also bolsters H2 content.
- Excess moisture (up to 1.5 times stoichiometric) minimizes particulate carbon formation.
- Hydrogen concentration 47% to 57% by volume.
- Approximately 1.8 to 2.0 Nm³ PCG/kg waste.
Plasma Processing of Medical Waste - Thermodynamics

- Thermodynamic analyses with air and CO/H2 as plasma media.
- Steam used to convert C to CO, also bolsters H2 content.
- Excess moisture (up to 1.5 times stoichiometric) minimizes particulate carbon formation.
- Hydrogen concentration 54% to 57% by volume.
- Approximately 2.3 to 2.6 Nm³ PCG/kg waste.
Thermodynamic analyses with air and CO/H2 as plasma media.
Steam used to convert C to CO, also bolsters H2 content.
Excess moisture (up to 1.5 times stoichiometric) minimizes particulate carbon formation.
Hydrogen concentration 50% to 53% by volume.
Approximately 4.5 to 5.5 Nm³ PCG/kg waste.
StarCell™ Hydrogen Separation and Purification Membrane

• Robust ceramic metal oxide membrane.
• Excellent material, chemical and thermal stability.
• Highly selective for H₂.
• Reasonable P&T operation.
• Patented product.
• Entering final development/commercialization phase.
StarCell™ Hydrogen Separation and Purification Module

- Individual membrane tubes are produced by the proprietary Thin Film Chemical Vapor Infiltration process.
- Tubes are potted together into a bundle.
- Each bundle is installed into a housing module.
StarCell™ Hydrogen Separation and Purification System

- Modules are connected together with three manifolds:
  - PCG In
  - H₂ Out
  - PCG Out
- A PCG heating section is integrated into the module chamber.

- StarCell™ equipment is installed in a standard cabinet enclosure.
- Instrumentation includes monitoring of the pressure and temperature of the three gas streams.
StarCell™ Performance

PCG Feed
100 units of Vol.
50.00%H₂
50.00%CO

Overall Feed
117 units
53.00%H₂
47.00%CO

Hydrogen Recovery Ratio & Purity (%)
80% & 91% 1st Stage
75% & 99% 2nd Stage
75% & 99% (<10 ppm CO) overall

Membrane #1
(1st Stage)

Membrane #2
(2nd Stage)

Byproduct using as plasma gas
62 units
20.00%H₂
80.00%CO

Feedback
17 units
73.00%H₂
27.00%CO

Product
38.00 units
~99%H₂
~1%CH₄
<10 ppm CO

Hydrogen Recovery Ratio & Purity of PCG
from StarCell™ - One Stage

Hydrogen Recovery Ratio & Purity of PCG
from StarCell™ - Two Stage

Hydrogen Purity vs. Recovery Ratio of PCG
from StarCell™ - One Stage

Hydrogen Purity vs. Recovery Ratio of PCG
from StarCell™ - Two Stage
StarCell™ Commercialization

- Preliminary economics indicate that distributed H\textsubscript{2} can be produced at a price very competitive with world-class steam/methane reforming plants.
- Depending on waste processed, H\textsubscript{2} cost is projected to be $\frac{1}{2}$ to 1 times the current production cost.
- Next step is a development/commercialization program:
  - Public sector cost sharing
  - Optimize StarCell™
  - Produce H\textsubscript{2} from actual PCG from waste materials
  - Fabricate industrial prototype
  - Beta site testing
- Startech expects commercial product in approximately 12 months.
In Summary

- PCS processes a wide range of feedstocks to produce PCG.
- Safer than environmental standards.
- StarCell™ separates out the Hydrogen from the PCG and similar mixtures.
- Undergoing final commercial development in the next 12 months.
- Revenue potential on front and back-ends.
Back-Up Slides
## Plasma vs. Incineration and Landfill

<table>
<thead>
<tr>
<th>Startech PCS</th>
<th>Incinerator</th>
<th>Landfill</th>
</tr>
</thead>
<tbody>
<tr>
<td>- &gt;1,400°C</td>
<td>- &lt;1,250°C</td>
<td>- Uncontrolled</td>
</tr>
<tr>
<td>- Produces Products</td>
<td>- Produces Wastes</td>
<td>- Produces Wastes</td>
</tr>
<tr>
<td>- Ultra Low Emissions</td>
<td>- Higher Emissions</td>
<td>- Very High Emissions</td>
</tr>
<tr>
<td>- Endothermic Process</td>
<td>- Exothermic Process</td>
<td>- Exothermic Process</td>
</tr>
<tr>
<td>- Rapid</td>
<td>- Rapid</td>
<td>- Very Slow</td>
</tr>
<tr>
<td>- 40% to 50% O.T.E.</td>
<td>- 15% to 25% O.T.E.</td>
<td>- Efficiency Not Measurable</td>
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<tr>
<td>- High Public Acceptability</td>
<td>- Very Low Public Acceptability</td>
<td>- Very Low Public Acceptability</td>
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Wastes as Resources

<table>
<thead>
<tr>
<th></th>
<th>wt%</th>
<th>Medical Waste (4,800 kWh/ton)</th>
<th>wt%</th>
<th>Used Tire (8,900 kWh/ton)</th>
<th>wt%</th>
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</thead>
<tbody>
<tr>
<td>MSW (3,100 kWh/ton)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Paper</td>
<td>25.97</td>
<td>Cellulose</td>
<td>18.40</td>
<td>Carbon black</td>
<td>30.50</td>
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<tr>
<td>Yard</td>
<td>8.25</td>
<td>Glass</td>
<td>11.04</td>
<td>Rubber</td>
<td>46.00</td>
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<tr>
<td>Food</td>
<td>7.43</td>
<td>Polypropylene</td>
<td>11.04</td>
<td>Sulfur</td>
<td>2.50</td>
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<tr>
<td>Plastics</td>
<td>7.16</td>
<td>Polyethylene</td>
<td>11.04</td>
<td>Nitrogen</td>
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<tr>
<td>Metals</td>
<td>5.32</td>
<td>Polystyrene</td>
<td>7.36</td>
<td>Steel</td>
<td>15.00</td>
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<tr>
<td>Rubber, leather, textile</td>
<td>4.50</td>
<td>Organic tissue</td>
<td>3.50</td>
<td>Ash</td>
<td>5.00</td>
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<td>Glass</td>
<td>3.75</td>
<td>Stainless steel</td>
<td>3.68</td>
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<td>Wood</td>
<td>3.61</td>
<td>PVC</td>
<td>3.68</td>
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<tr>
<td>Others</td>
<td>2.18</td>
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<tr>
<td>Moisture</td>
<td>31.84</td>
<td>Moisture</td>
<td>30.25</td>
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<tr>
<td>Total</td>
<td>100.00</td>
<td></td>
<td>100.00</td>
<td></td>
<td>100.00</td>
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</tbody>
</table>

- Current practices lead to harmful emissions and wasting of resources.
- With the Startech process:
  “Where there are people there is waste. Where there is waste, there is hydrogen. We can distribute hydrogen where it is needed.”
Specific Energy Required

- The energy required to process a given waste stream depends on the properties of the specific waste.
- Empirical data for various wastes is as follows:

<table>
<thead>
<tr>
<th>Materials</th>
<th>kWhr/tonne</th>
<th>10^3 BTU/ton</th>
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<tbody>
<tr>
<td></td>
<td>[min.]</td>
<td>[max.]</td>
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<tr>
<td>Steel scrap melting</td>
<td>584</td>
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<td>Pyrolysis of hospital waste</td>
<td>595</td>
<td>1101</td>
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<td>Pyrolysis of PCB oil</td>
<td>441</td>
<td>1212</td>
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<td>Pyrolysis of MSW</td>
<td>771</td>
<td>1542</td>
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<td>Pyrolysis of auto tires</td>
<td>1872</td>
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<td>Pyrolysis of pathological wastes</td>
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<td>1968</td>
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<td>EAF dust treatment</td>
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<td>1927</td>
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<td>Niobium recovery</td>
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<td>3194</td>
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<td>PGM recovery from auto catalyst</td>
<td>3029</td>
<td>4405</td>
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<tr>
<td>Ceramic production</td>
<td>2533</td>
<td>15022</td>
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